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Technology Development, Demonstration and Orbital Support Requirements for Manned Lunar and Mars Missions

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TECHNOLOGY NEEDS DEVELOPMENT AND ORBITAL SUPPORT REQUIREMENTS FOR MANNED LUNAR AND MARS MISSIONS

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ABSTRACT

This paper will present an overview of the critical technology needs and the Space Station Freedom(SSF) focused support requirements for the Office of Exploration's(OEXP) manned lunar and Mars missions. Major emphasis will be directed at the technology needs associated with the low Earth orbit(LEO) transportation node assembly and vehicle processing functions required by the lunar and Mars mission flight elements. The key technology areas identified as crucial to support the LEO node function to be discussed in this paper include in-space assembly & construction, in-space vehicle processing & refurbishment, space storable cryogenics and autonomous rendezvous & docking.

INTRODUCTION

In early 1987, NASA Headquarters requested that the Langley Research Center's Space Station Freedom Office perform studies to assess the impact of manned lunar and Mars missions on the baseline Space Station Freedom(SSF). Agency-wide teams were formed to investigate the Station support necessary to accommodate such missions with emphasis on the precursor research, overall mission support in LEO, concurrent science requirements and impacts, technology needs and demonstration requirements and resource demands on station crew, power, volume and facilities. The results of these studies are published in references 1 and 2.

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Impetus was given to the exploration program in a directive issued by President Bush in July of 1989 to have a human presence on the Moon and Mars in the 21st century. The President announced a pathway to a Mars outpost by way of the Moon and a study process has been developed and implemented to accomplish this goal. (See references 3 and 4.)

CASE STUDIES OVERVIEW

For the Fiscal Year 1989(FY89) the Case Studies set by the Office of Exploration(OEXP) included two Mars and one Lunar scenario. A top level summary of these scenarios is shown in table 1.

TABLE 1. SUMMARY OF CASE STUDIES FOR FISCAL YEAR 1989

	Lunar Evolution (CS 4.1)	Mars Evolution (CS 5.0)	Mars Exped (CS 2.1)
Crew Size	8	5, 7	3
Staging node	SSF	dedicated new LEO node	none
Reusability of piloted vehicles	yes	yes	no
Aerobrake			
Use	at Earth	Mars, Earth	Mars only
Type	low L/D	low L/D	L/D = 1.0
Orbit at target body	LLO	Phobos (Gateway)	LMO
Trajectories			
Cargo	from SSF	Conjunction	Conjunction
Piloted	from SSF	Opposition & Conjunction	Sprint
ETO pipeline constraints			
Wet	570 t/yr	570 t/yr	570/yr
Dry	90 t/yr	90 t/yr	-
Propulsion			
Cargo	Chemical NEP, 2014	Chemical NEP, 2014	Chemical -
Piloted	Chemical	Chemical NTR, 2014	Chemical
In situ Resources Utilization	LLOX	Phobos LOX	none

In all of the FY89 Case Studies scenarios, major mission cargo is delivered to LEO on unmanned launches that occur at distinct intervals from the manned or piloted launches. A detailed description on each case may be found in reference 4.

In the Mars scenarios, the HLLV's payload and volume constraints drove the requirement for in-space assembly and construction capability at the node. In the lunar cases, where the flight rates were high, the lunar transfer vehicles were reusable. The need to process and service this reusable flight hardware on-orbit drove the requirement for an in-space vehicle processing/refurbishment capability.

TECHNOLOGY REQUIREMENTS/NEEDS

The top level technology requirements/areas needed to support manned lunar and Mars exploration missions are shown in figure 1. Although generic in nature, these requirements are relevant to both the lunar and Mars case studies. The technologies indicated on the figure are applicable to three key technical study areas which are: transportation node systems; transfer vehicle systems; and, extraterrestrial systems. The technologies were not time-phased nor prioritized but served as a point of departure in the studies for determining areas where additional emphasis was required. The remainder of this paper will concentrate on those technologies that are relative to the LEO transportation node function.

To provide better visibility and traceability to the technology needs evolving from the case study activity, the Exploration Technology Working Group (ExTWG) was formed with representatives from the various NASA centers, the Office of Exploration and the Office of Aeronautics & Space Technology. These representatives were designated as Technology Integration Agents(TIA's).

Analysis of the OEXP FY89 Case Studies by the ExTWG identified some fifty-six technology needs within the three key technical study areas mentioned earlier. All of the technologies were then ranked by the ExTWG TIA's and their recommendations were presented to the OEXP Technology Manager and the OEXP Technology Director. The results of this process are beyond the scope of this paper, however, the details of the analysis can be found in reference 4.

In the process of developing the technology needs for the three key technical study areas i.e., transportation node systems, transfer vehicle systems and planetary surface systems, it was found that there were specific technologies that were common to all of these key technical areas. These common or "crosscutting" technologies were Automation, Robotics, Maintainability, Operability and FDIR (fault detection, isolation and recovery). Table 2 depicts a top level overview of the crosscutting technologies associated with the transportation node technology areas. As can be seen in the table the crosscutting technologies are common to all of the major technology areas identified for the node systems.

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- o ADVANCED ENVIRONMENTAL CONTROL AND LIFE SUPPORT SYSTEM (ECLSS)
  - AIR, WATER, WASTE MANAGEMENT, FOOD PROCESSING
- o CREW SYSTEMS
  - ADVANCED EVA SUITS
  - HABITABILITY CONSIDERATIONS
  - HEALTH CARE AND MAINTENANCE CONSIDERATIONS
- o SURFACE TRANSPORTATION
  - ROVERS (UNMANNED, MANNED)
- o AUTOMATION AND ROBOTICS
  - CARGO HANDLING
  - ASSEMBLY
  - REMOTE SITE EXPLORATION
- o PROPULSION
  - CHEMICAL
  - NUCLEAR
  - SOLAR
- o STRUCTURES
  - AEROBRAKE/AEROSHELL
  - ASSEMBLY AND HANDLING
- o POWER/THERMAL
  - SOLAR
  - NUCLEAR
  - CHEMICAL
- o LONG-TERM PASSIVE STORAGE MISSION SYSTEMS/SUBSYSTEMS
  - RADIATION/TEMPERATURE EFFECTS
  - PROPELLANT STORAGE
  - MAINTENANCE/ACTIVATION

Figure 1. Top Level Exploration Missions Technology Areas

TABLE 2. CROSSCUTTING TECHNOLOGIES TRANSPORTATION NODE

Technology	Automation	Robotics	Maintainability	Operability	FDIR
In-Space Vehicle Processing/Servicing	X	X	X	X	X
Cryo Fluid Storage/Management	X	X	X	X	X
In-Space Assembly - Vehicle Level	X	X	X	X	X
Autonomous Rendezvous/Docking	X	X	X	X	X
In-Space Assembly - Element Level	X	X	X	X	X

The major technology needs associated with the transportation node systems definition, and the attendant infrastructure requirements, including the space station, needed to support the exploration missions are discussed in the following paragraphs. However, from the transportation node viewpoint, it was found that the technology requirements identified were relatively insensitive to the particular mission, or case study, under analysis. Generally, the only major differences between the requirements for the lunar and Mars case studies were the specific technology need dates. That is, the technology readiness level requirements were keyed to a particular case study's program and milestone schedule.

The top level technology areas unique to the LEO transportation node function are summarized in figure 2.

- o **IN-SPACE ASSEMBLY**
    - **ASSEMBLY OF LARGE AEROSHELLS**
    - **ASSEMBLY OF LARGE SPACE TRANSFER VEHICLES**
    - **JOINING OF LARGE STRUCTURAL ELEMENTS (HANGARS, PROPELLENT STORAGE FACILITIES, ETC.)**
    - **AUTOMATION/TELEROBOTIC PRINCIPLES (PRECISION POSITIONING/ HANDLING)**
- o **IN-SPACE VEHICLE PROCESSING/REFURBISHMENT**
    - **A&R/TELEROBOTIC TECHNIQUES & AIDS**
    - **AUTOMATED SYSTEMS TEST & CHECK-OUT**
    - **FAULT TOLERANT SYSTEMS**
    - **IN-SPACE SERVICING/DESERVICING & CHECK-OUT OF "WET" SYSTEMS (HYPERGOLS)**
- o **CRYOGENIC FLUID MANAGEMENT & TRANSFER**

Figure 2. LEO Transportation Node Top Level Technology Areas

To accommodate the in-space assembly & construction needs associated with the LEO node, the capability to assemble, handle, and mate/demate very large, very massive and complex space vehicle and vehicle elements will be required. A high degree of confidence and reliability must be demonstrated and assembly/ construction operations must be conducted with minimum risks and minimum crew involvement, especially EVA. For the exploration space vehicles/elements (aeroshells, spacecraft, propulsion systems, interface structures, etc.), the on-orbit technology program must address handling, assembly and mating techniques using large capacity, highly articulated manipulators and robotic/telerobotic aids. The success of providing this capability depends upon major advancements in the discipline technology areas such as automation & robotics, telerobotics, development of advanced processes for joining/mating space vehicle elements & components(welding, bonding, snap connectors, etc.); and the associated controls-structures interactive systems necessary to maintain the close tolerances required while minimizing disturbances to the structure(s) and vehicle(s).

The in-space vehicle processing/refurbishment function, will require many of the same attributes needed by the in-space assembly/construction function, i.e., handling, mate/demate, manipulating large and massive mission elements with great precision. In addition to the integration and checkout functions, the capability to service/deservice, maintain, repair and refurbish all reusable flight hardware elements must be developed and demonstrated in the space environment. Technology issues associated with this on-orbit function include advancements in such areas as automation and robotics/telerobotics, automated systems test & checkout(fault-tolerant systems), on-orbit test, service/deservice checkout equipments/ hardware. Crew roles and interfaces must be an integral element in the design, development, test and engineering(DDT&E) process. In addition, when nuclear vehicles become part of the transportation inventory, research and technology programs will be needed to support remote/autonomous inspection, maintenance, servicing and checkout of the departing and returning spacecraft.

To accomplish on orbit what has traditionally been done using ground-based facilities will require a whole new set of in-space operational philosophies, procedures and orbital support equipments especially where manned systems are involved.

From a key technology standpoint, the capability to deliver and maintain large quantities of cryogenic propellants in space for long periods of time must be developed and demonstrated in the actual space environment before any of the proposed missions can seriously be considered. The major space cryogenic tec hnology issues are the fluid storage, transfer, handling and management. Solutions to these issues are keyed to advancements in the supporting technology areas of automation and robotics and autonomous rendezvous and docking. From a "safe systems operations" standpoint, the propellant storage will probably be on a coorbiting facility and hence, the transfer, delivery and handling of these propellants will have to be conducted remotely.

Additionally, liquid slosh dynamics and control during docking and/or deployment of spacecraft with the propellent facility must be understood. In addition, methods for providing safe cryogenic tankage/storage prior to EVA proximity operations or emergency propellent dumps must be developed and fuel, oxidizer mixing must be avoided. System design criteria must also be established in the development of the cryo storage systems in order to minimize systems weight, understand systems integration(thermal/structural), provide high reliability, determine repeatable in-space fabrication techniques and assess potential material contaminants.

Autonomous Rendezvous and Docking(AR&D) is another key technology driver in implementing the exploration missions, particularly the planetary expeditions. For LEO node operations, this capability will be needed as traffic in the Command & Control Zone (CCZ) of the space station increases in order to accommodate the OEXP missions. For the lunar and Mars orbital operations suggested by the case study scenarios, the ability to perform this function totally autonomously (without any human intervention) is truly enabling primarily because the round-trip-light-time(RTLT) delays in deep space communications preclude Earth-based support.

THE ROLE OF SPACE STATION FREEDOM

A major Space Station Freedom (SSF) program goal is to design a facility capable of growth that will support future mission requirements and long-term national goals such as the human exploration initiatives.

The following discussion will concentrate primarily on the Lunar Evolution Case Study and how the Station may evolve to support this one particular case study.

Figure 3 shows the baseline Space Station Freedom "Assembly Complete"(AC) configuration scheduled to be operational in mid-1998. The station at this stage will have somewhat limited resources but will have the capability for growth as user needs and national goals mature. Briefly, it will support a crew complement of eight, provide up to 75kw of power and heat rejection with appropriate scars for addition of Solar Dynamic arrays and provisions for habitat/laboratory growth and utilities.

The transportation node resource requirements developed for the Lunar Evolution Case Study are shown in figure 4. Figure 5 depicts the time-phased station "growth deltas", or additions to the baseline station, necessary to meet the requirements shown in the previous figure.

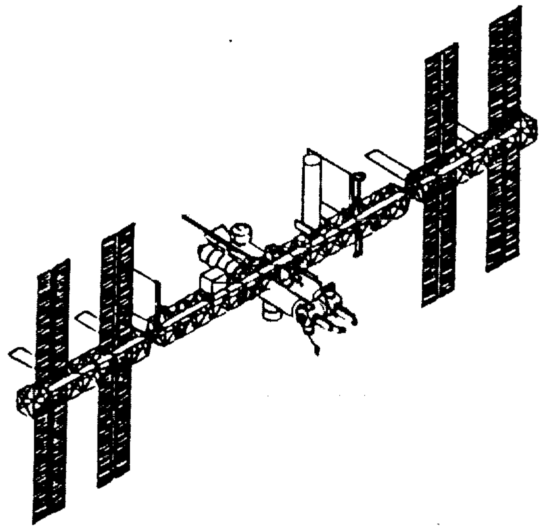

Figure 3. Space Station Freedom Assembly Complete Configuration.

Station Configuration	Recommendation
Power	
Average	175kw
Peak	(NA)
Crew	18
Pressurized Modules	
US Habitation	2
US Laboratory	1
ESA Laboratory	1
JEM Laboratory	1
Pocket Laboratory	1
Resource Node	1
Dual Keel	Scar for distributed systems
Servicing Facility	Scar for all possible locations
Power Modules	SD array growth on extensions of boom ends
Attached Payload	(TBD)
Accom. Equip.	
Tether Payloads	2

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Figure 4. Transportation Node Resource Requirements

Δ1 (2 - 25kw) Solar Dynamic Modules; (2) 25 meter Transverse Boom Extensions; Space Based OMV & Space Based OMV accommodations

Δ2 Upper/Lower Keels & Booms; Utility Trays

Δ3 (1) Habitat Module; (2) Resource Nodes

Δ4 (2 - 25 kw) Solar Dynamic Modules; Servicing Facility Phase I

Δ5 Servicing Facility Phase 2

Δ6 Phase 1 STV Processing Facility; Phase 3 Servicing Facility (Completed CSF); (1) Mobile Servicing Center (MSC)

Δ7 Additional Lower Keel and Boom

Δ8 Part 2 LTV Processing Facility (LTV Processing Facility complete)

Figure 5. Time-Phased Station "Growth Deltas"

Figure 6 shows the Lunar Evolution Space Station reference configuration. The vehicle assembly, servicing and processing facilities are accommodated in an enclosed hangar attached to the lower keels and booms of the station. The station/node is capable of processing/storing two lunar transfer vehicles simultaneously.

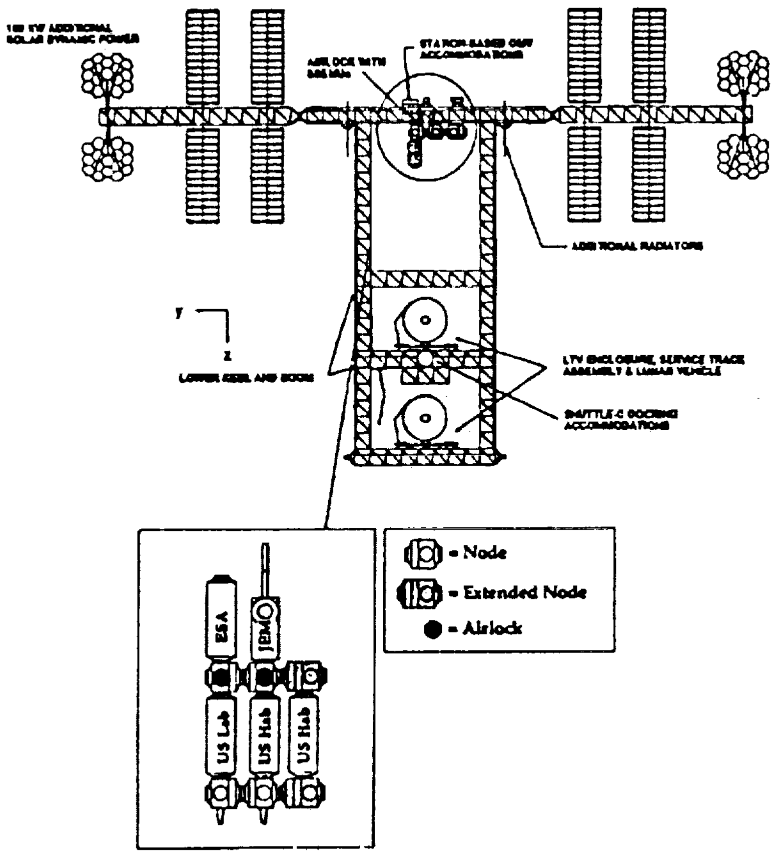

Figure 6. Lunar Evolution Space Station Reference Configuration.

Figure 7 shows the Space Station Freedom baseline and the evolution schedules and milestones for the exploration initiatives.

As the figure indicates, the evolution planning is currently in progress. Emphasis at this time is on design requirements leading to an evolution development decision for Phase A/B studies in late CY '90 or early CY '91. This decision point is key since the evolution Phase C/D activities must begin by mid-CY '94 in order to have the growth station operational for a manned lunar mission in the year 2004.

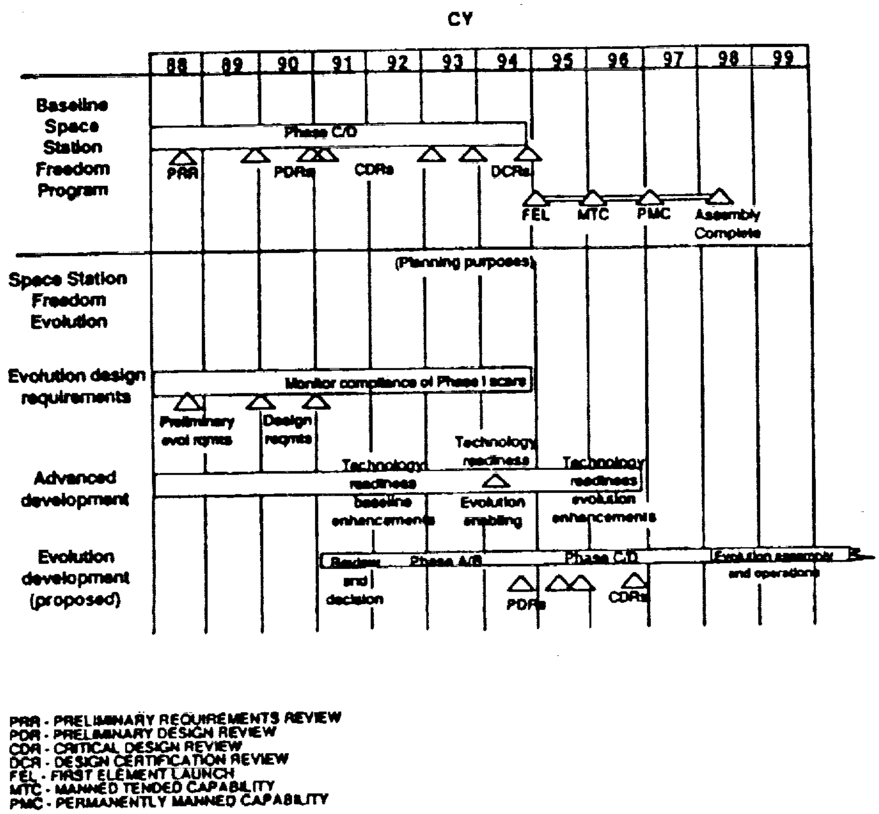

Figure 7. Space Station Freedom Evolution Schedule, Milestones

In addition to the technology development and operational support required by the station, the importance of demonstrating and validating the "serviceability" feature of each of the flight elements cannot be overemphasized. The ability to service and process the vehicle on-orbit in a timely and efficient manner with the high degree of confidence required for safe operations and mission success, is going to be a real challenge to both designers and operators alike.

End-to-end testing and all-up mission simulations with the totally integrated lunar vehicle configuration will also be required.

SUMMARY

Top level technology needs have been identified from a review of material presented in studies related to the Office of Exploration's (OEXP) transportation node activities and selected supporting study work from the Office of Space Station (OSS). The major technology needs associated with the transportation node system definition and the attendant infrastructure requirements needed to support the exploration mission have been developed.

Space Station Freedom activities required to support the Lunar Evolution Case Study have been addressed in some detail. However, it should be noted that the lunar initiative is essential to the pathway to Mars announced by the President and the Station evolution planning discussed in the paper reflects this direction.

The major role for the Station in the human exploration initiatives program will be the on-orbit technology development, testing and verification of the flight hardware and the in-space assembly and vehicle servicing/processing function development. The operational phases of the programs will require significant Station support for the assembly, processing, maintenance and refurbishment of the lunar and/or Mars mission hardware.

A commitment to provide the extensive LEO node support capability just discussed will require considerable study and major management decisions. In addition to the technological and engineering challenges mentioned above, two important factors will undoubtedly influence the decision process. These are the specific mission designs and the ability to demonstrate and subsequently conduct the many in-space operations required to implement and effectively sustain the proposed exploration missions.

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16. Abstract

This paper will present an overview of the critical technology needs and the Space Station Freedom (SSF) focused support requirements for the Office of Exploration's (OEXP) manned lunar and mars missions. Major emphasis will be directed at the technology needs associated with the Low Earth Orbit (LEO) transportation node assembly and vehicle processing functions required by the lunar and mars mission flight elements. The key technology areas identified as crucial to support the LEO node function to be discussed in this paper include in-space assembly & construction, in-space vehicle processing & refurbishment, space storable cryogenics and autonomous rendezvous & docking.

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